Preservation of juvenile hake (*Merluccius merluccius*, L.) in the western Mediterranean demersal trawl fishery by using sorting grids*

FRANCESC SARDÀ, BALBINA MOLÍ and ISABEL PALOMERA

Institut de Ciències del Mar (CSIC), Passeig Marítim de la Barceloneta 37, 08003 Barcelona. E-mail: siscu@icm.csic.es

SUMMARY: The Mediterranean fishery has experienced a decline in catches over the past 20 years due to an excessive increase in effort caused by both increased trawler engine power and rapid technological advances in fishing technology and fish location. This has led to overexploitation, in which immature individuals support an increasing portion of the catches. The present study was undertaken to test a sorting grid and square-mesh-panel as juvenile exclusion systems. Our experience was a pilot study of such a system in the western Mediterranean. The purpose of these exclusion systems was to help juvenile hake escape from the net. The results demonstrate that the use of sorting grids for small fish in trawl gears in the Mediterranean is an efficient and practical means of avoiding the capture and discarding of unwanted individuals, with escape rates of over 50% (ranging between 50 and 90%). The grids were efficient and useful for excluding hake (*Merluccius merluccius*) on bottoms located at depths between 50 and 300 m, where hake are found all year round. A bar spacing of 20 mm yielded escape rates of L_{50} at 18.8 cm TL (L_{25} = 16.8 cm and L_{75} = 20.9 cm). Panels made of square meshes achieved poorer results than the grids. The grid system was effective for most of the species caught in the study area.

Key words: trawling, sorting grids, square mesh, selectivity, hake, *Merluccius merluccius*, juveniles, Mediterranean Sea.

RESUMEN: PRESERVACIÓN DE JUVENILES DE MERLUZA (*MERLUCCIUS MERLUCCIUS*, L.) EN LA PESQUERÍA DEMERSAL DE ARRASTRE DEL MEDITERRÁNEO OCCIDENTAL, MEDIANTE EL USO DE REJILLAS SEPARADORAS. – Durante los últimos 20 años la pesca en el Mediterráneo ha experimentado un descenso de capturas al mismo tiempo que se detecta un excesivo incremento del esfuerzo, tanto en potencia de las embarcaciones como en avances tecnológicos y de detección de peces. Esto lleva a la sobreexplotación de crecimiento en la cual las capturas recaen principalmente sobre los individuos inmaduros. Este estudio pretende probar varias rejillas separadoras y paños de malla cuadrada como sistemas de exclusión de juveniles en artes de arrastre de fondo, lo cual constituye una primera experiencia piloto en el Mediterráneo. El objetivo del uso de las rejillas y mallas cuadradas es permitir el escape de juveniles de merluza en cantidad y en buenas condiciones. Los resultados demuestran que el uso de los sistemas selectivos rígidos constituye una buena solución, efectiva y práctica, para reducir drásticamente los descartes de especies no deseadas. Las tasas de escape calculadas superan el 50% de los ejemplares pequeños (entre el 50 y el 92%). Estos sistemas fueron muy eficientes para la merluza en fondos entre 50 y 300 m donde se distribuye durante la mayor parte del año. El espacio entre barras fue de 20 mm, el cual produjo tallas de L_{50} de escape de 18.8 cm (L_{25} = 16.8 cm y L_{75} = 20.9 cm). La malla cuadrada dió peores rendimientos de escape que las rejillas.

Palabras clave: pesca de arrastre, rejillas, malla cuadrada, selectividad, merluza, *Merluccius merluccius,* juveniles, Mediterráneo.

INTRODUCTION

Selection methods based on increasing the size of traditional diamond-shaped meshes have often failed to improve the escapement of juveniles because diamond meshes stay tightly closed during trawling and individuals that escape through these meshes may suffer high mortality rates (Suuronen, 1995; Suuronen *et al*., 1996; Figuerola *et al*., 2001). Furthermore, there is evidence that post-selection

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survival can be improved by using fish sorting grids in trawl gears (Broadhurst *et al*., 1996; Suuronen *et al*., 1996; Broadhurst *et al*., 1999). Accordingly, countries in northern Europe and America are developing sorting grids to improve size selection of fishes, allowing juveniles to escape through the net with minimal injury and stress before they enter the codend (Larsen and Isaksen, 1993; Chopin and Arimoto, 1995; Lehtonen *et al*., 1998; Valdemarsen and Suuronen, 2003).

Technology based on fish sorting grids was developed in different parts of the world in the 1990s for various purposes, ranging from excluding large protected species such as sharks and turtles (Villaseñor, 1997) to allowing the escape of juveniles, in particular hake, in South America (Ercoli *et al*., 1997), or pelagic species (Kvalsik *et al*. 2002), as well as merely separating certain species of crustaceans, e.g. shrimps (Isaksen *et al*., 1992, Broadhurst *et al*., 1996; Ercoli *et al.,* 1997; Polet, 2002; Graham, 2003).

Other methods based on gear designs that include square meshes or escape windows in different parts of the net have been tried for various species (Ulmestrand and Larsson, 1991; Briggs, 1992; Campos *et al*., 1996; Broadhurst, 2000; Halliday and Cooper, 2000; Madsen *et al*., 2001; Massutí *et al*., 2002; Campos *et al*., 2003). The effect of towing speed and gear size on the selectivity of bottom trawl nets has also been tested (Dahm *et al*., 2002).

The Mediterranean fishery has experienced a decline in catches over the past 20 years due to an excessive increase in effort caused by both increased trawler engine power and rapid technological advances at all levels (vessels, nets, mechanical plant, electronic equipment, etc.) (Bas, 2003; Maynou *et al*., 2003). This has led to what is known as growth overexploitation, in which immature individuals (particularly hake) support a significant portion of the catches (Oliver, 1991; Recasens, 1992; Lleonart, 1993; Irazola *et al*., 1996). The small sizes are caught around the year by a high proportion of bottom trawlers with medium and high engine power (200-800 HP), at depths ranging between 50 and 300 m depth. While sales of these small sizes are prohibited, there is nonetheless a landing dynamics that is invariably difficult to control and correct. The actual difficulty is not just the sales of illegal catches but the discards produced by this practice. Small, immature individuals of different species, and particularly hake, are often discarded dead before a vessel returns to port, either because large catches cannot be sold or because small individuals are damaged and are thus unsuitable for sale. This situation applies to a variety of Mediterranean species, but small hake inhabiting the depth zone between 50 and 300 m are those that are hit hardest.

TABLE 1. – Haul characteristics. Grid type, explanation in the text.

Grid type	Haul number	Date	Trawl starting position Latitude N	Trawl starting position Longitude E	Depth (m)	Speed (knots)	Towing duration (min)	Time of fishing (h)	Trawl final position Latitude N	Trawl final position Longitude E
A	1	10/06/02	41.15	1.80	70.0	3.8	55	7:45	42.15	1.84
A	2	10/06/02	41.14	1.75	70.0	3.7	55	10:25	41.14	1.67
A	3	10/06/02	41.12	1.75	70.0	3.7	60	12:45	41.13	1.83
B	4	11/06/02	41.18	2.07	80.0	3.8	75	9:00	41.23	2.15
B	5	11/06/02	41.24	2.12	70.0	3.7	90	12:40	41.02	2.02
C	6	12/06/02	41.13	1.83	50.0	3.9	60	8:15	41.14	1.90
C	7	12/06/02	41.13	1.80	70.0	3.5	60	11:30	41.13	1.72
C	8	12/06/02	41.13	1.72	70.0	3.8	70	13:35	41.12	1.78
D	9	13/06/02	41.13	1.78	70.0	3.6	70	7:50	41.12	1.70
D	10	13/06/02	41.13	1.10	70.0	3.7	95	10:00	41.13	1.84
D	11	13/06/02	41.13	1.87	70.0	3.5	60	13:05	41.13	1.80
D	12	14/06/02	41.15	1.84	50.0	3.6	60	8:00	41.13	1.80
D	13	14/06/02	41.17	2.42	250.0	3.7	55	10:10	41.20	2.17
D	14	14/06/02	41.17	2.15	300.0	3.6	55	12:45	41.15	1.03
A	15	17/06/02	41.10	1.98	250.0	3.5	60	8:20	41.10	2.00
A	16	17/06/02	41.17	2.10	250.0	3.6	55	11:15	41.20	3.03
A	17	17/06/02	41.19	2.13	250.0	3.8	55	13:25	41.05	2.05
A	18	18/06/02	41.14	1.77	70.0	3.7	80	7:45	41.12	1.75
A	19	18/06/02	41.13	1.83	80.0	3.5	55	10:10	41.02	2.03
B	20	18/06/02	41.15	1.88	50.0	3.7	85	12:45	41.14	1.77
C	21	19/06/02	41.05	1.78	300.0	3.4	50	8:10	41.05	1.85
C	22	19/06/02	41.05	1.77	250.0	3.6	45	10:20	41.07	1.82
C	23	19/06/02	41.13	1.90	70.0	3.6	80	12:40	41.14	1.79
B	24	21/06/02	41.15	1.67	50.0	3.7	70	8:00	41.13	1.77
C	25	21/06/02	41.13	1.84	70.0	3.7	80	10:55	41.13	1.72

Studies and simulations of escape systems for Mediterranean hake (Cheret *et al.*, 2002) suggest that allowing the escape of small fish should bring about a 30 to 50% increase in catches of larger individuals four or five years after implementation of the system.

The present study was undertaken to test a sorting grid exclusion system for trawl gears and to carry out a pilot study of the system in the western Mediterranean. The purpose of the grid exclusion system was to help juvenile hake escape from the net in good physical condition so as to ensure their survival. Finally, the efficiency of different grids and square mesh sizes was compared in terms of escape of juvenile hake and other species.

MATERIALS AND METHODS

The study area comprised depths between 50 and 300 m in the fishing grounds off the fishing port of Vilanova i la Geltrú (Catalan coast, western Mediterranean), where juvenile hake occur frequently. The trials were performed in June 2002. This time of year was chosen because it is the time of greatest abundance of small hake in the study area. A total of 25 hauls were carried out from the commercial trawler "José y Virgilio" (19.5 m long, 43.4 t GRT). The mean speed during hauls was 3.8 ± 0.1 knots. Table 1 summarises the details of each haul, giving position, depth, and duration.

Hake (*Merluccius merluccius*) was the target species for this study because of its high economic importance and abundance. It is also considered a major target species in the management framework of the General Fisheries Council for the Mediterranean.

The sorting grids were installed in one of the nets of a twin trawl gear design supplied by the company SALOM, S.L. Three different grids were tested, designated A (Fig.1 and 5A), B (Fig. 2 and 5B) and C (Fig. 3 and 5C). In addition, the efficiency of these grids was compared to the performance of a 4 m long x 1 m wide square-mesh panel (D, Fig. 4 and

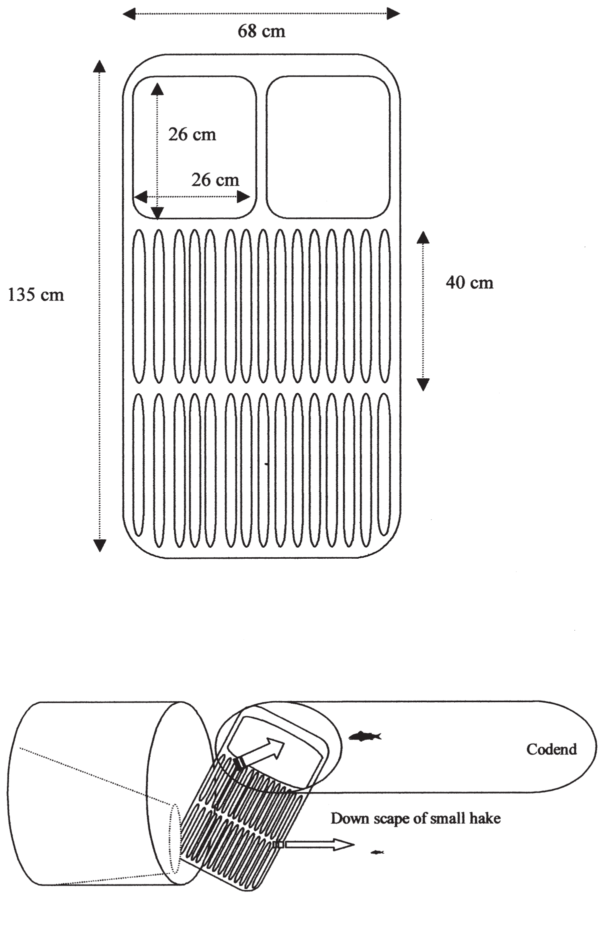

FIG. 1. – Scheme of grid A (20 mm bar separation). Big fishes are diverted to codend (Fig. 5A).

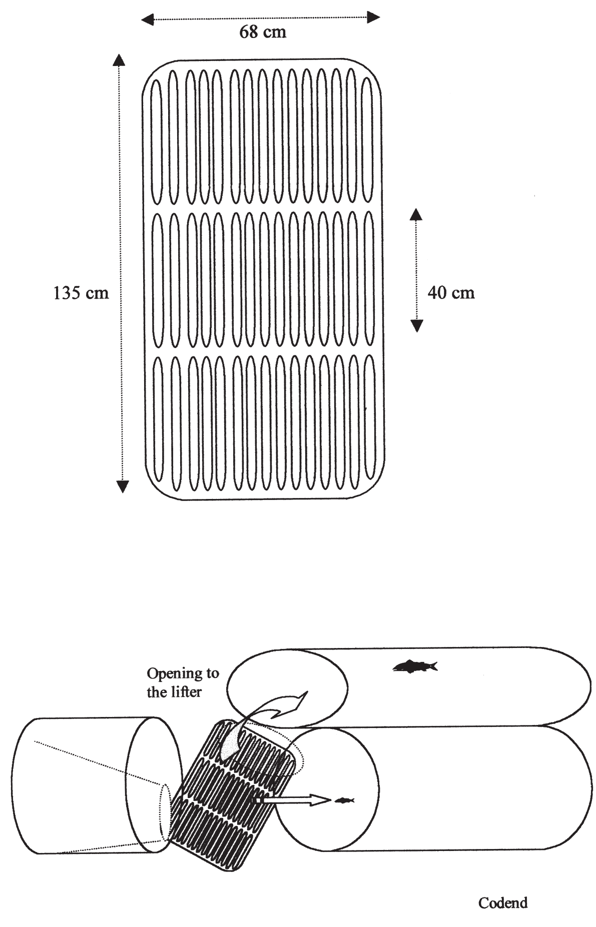

FIG. 2. – Scheme of grid B, device for big fishes on top (20 mm bar separation) (Fig. 5B).

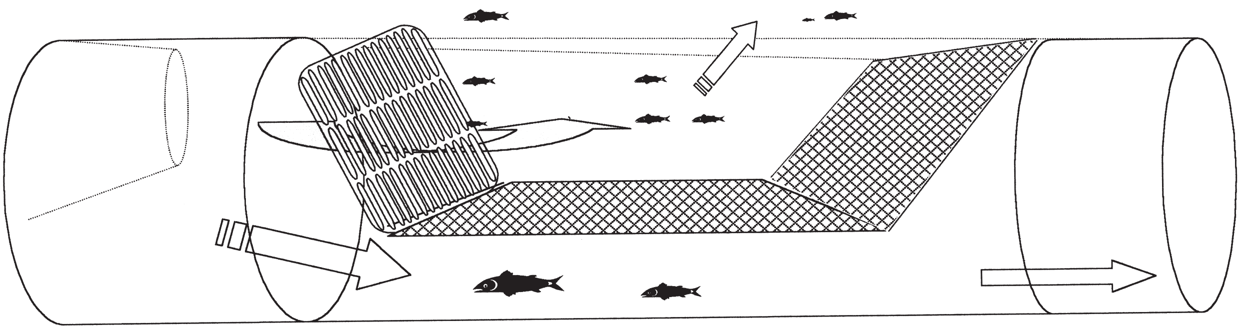

FIG. 3. – Scheme of grid C (model Sort-X). 20 mm bar spacing (Fig. 5C).

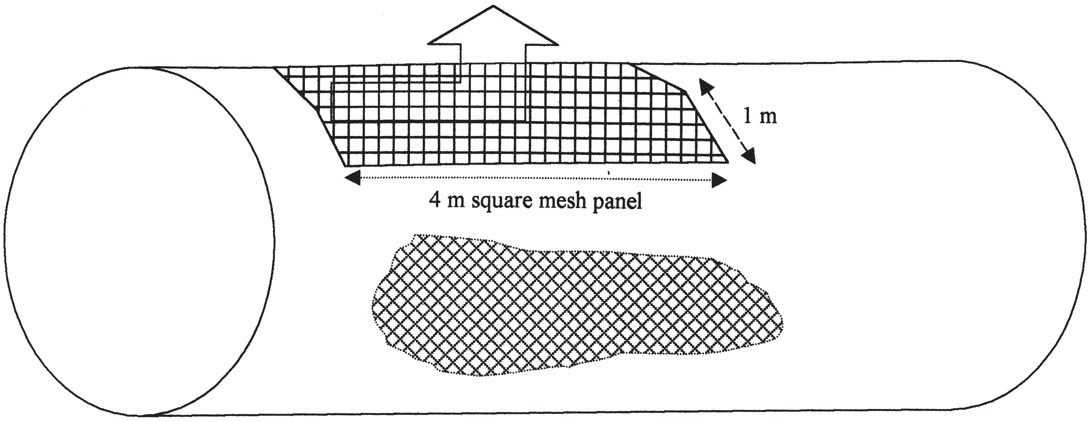

FIG. 4. – Location of square mesh panel D on extension gear (20 mm side) (Fig. 5D).

5D), attached to the upper part of the extension and in front of the codend.

The grids were made of rigid plastic (135 cm high x 68 cm wide) and were installed in the extension piece in the net, 5 m ahead of the codend (Fig. 6). Installation was performed according to Isaksen *et al*. (1992) and Ercoli *et al*. (2000). All the grids and the square mesh panel allowed juveniles a direct outlet to escape from the codend except in version B, in which small fish passing through the grid were directed into the codend, while larger fish were directed into an extra codend on the upper portion of the net (see Fig. 2), to allow monitoring of grid selectivity.

Spacing between bars was 20 mm, the same as the length between two knots in the diamond-shaped netting that is legal in the Mediterranean. The mesh was made from high-strength knotless Dynema fibre (40 mm stretch mesh). The grids were equipped with a bracket for attaching the Scanmar sensor used to measure the angle between the grid and the bottom during trawling.

A twin gear consisting of two identical trawls that fished in parallel was designed to test grid efficiency. The twin trawl is commonly used for selectivity tests using different selective systems (Graham *et al*., 2003). The trawls were towed by two warps, each ending in a crowfoot to which the trawl was connected. A weight in the centre was used to keep the gear balanced. The trawl doors were a MAPSA Model HIP-SE P-95, 2.40 x 1.38 m in size and 500 kg in weight. Each gear was especially constructed for this experience with similar characteristics to the commercial ones.

Grids were installed in one of the trawls, with the other trawl using the ordinary diamond-shaped mesh (40 mm, stretched mesh). Towing time was approximately one hour, and the hauls were carried out at depths between 50 and 300 m. Between four and six tows were done each day with each grid (Table 1). Rig measurements under working conditions were taken with the aid of two sets of remote Scanmars. The sensors measured gear height, mouth opening between wings, door spread and grid angle.

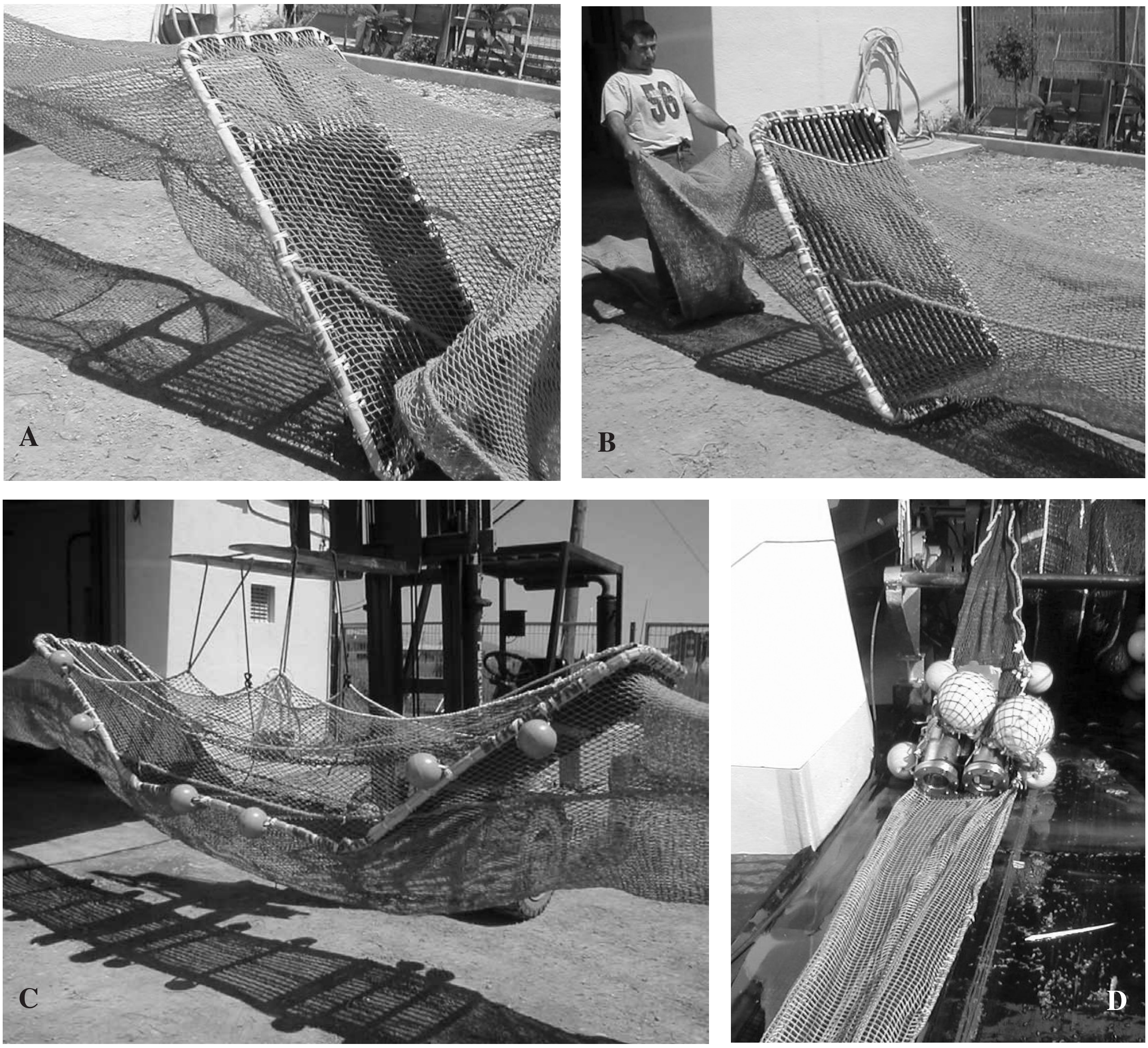

FIG. 5. – Photos A, B, C and D correspond to different grids of the Figures 1, 2, 3 and 4 respectively.

The mean values are represented in Figure 6. The sensor was moved to be able to measure the distance between the two inside wings on the twin trawl rigs or between the central weight and one of the doors.

Data were processed separately for each individual haul. The catch was sorted on board by trawl rig and weighed (kg ± 1) using a digital dynamometer. Total length to a precision of 1 cm (± 0.5) was measured for all specimens of the target species. In those cases in which sample catches were very large, proportional weight sub-samples were taken by species and sizes (small or large specimens, see text below).

Total catch by species was weighed and measured individually by codend capture origin (with/without grid). The data were used to produce plots in number and percentage of individuals by grid type, haul and species, with special attention being concentrated on small hake. In most cases the number of individuals was used for the plots, because it was deemed to be a more exact measure than weight. Weight measurements were affected by vessel motion and also increased the error in samples composed of a small number of specimens. Hauls were disregarded where samples were judged to be unrepresentative. Grid efficiency was compared based on the differences between the hauls made using the same grid type and without grid or square mesh. A non-parametric Kruskal-Wallis test ($p < 0.05$) was performed to detect statistically significant differences between escapes of different grids.

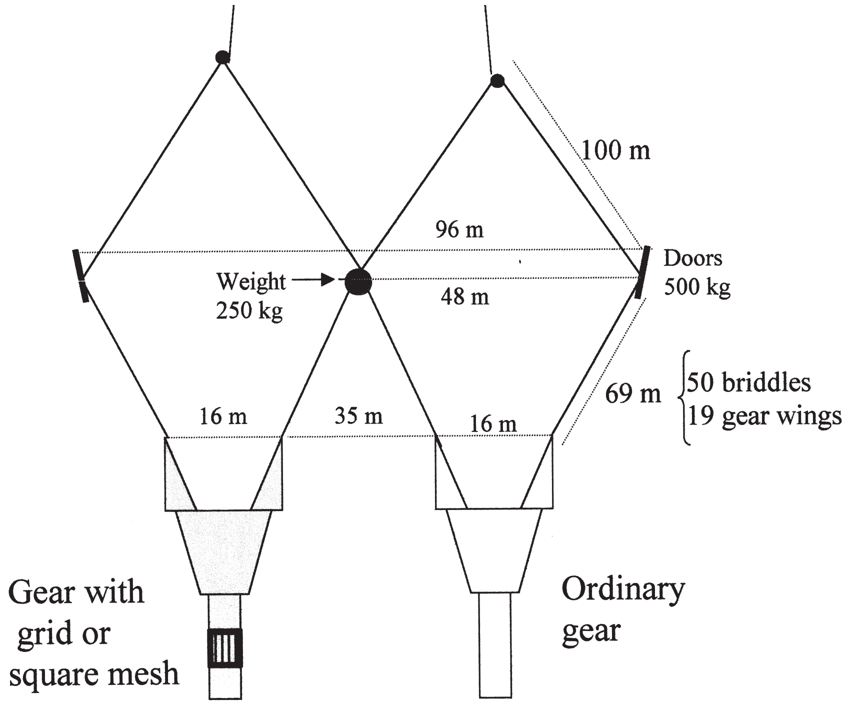

FIG. 6. – Diagram of the twin trawl used in the experiment.

A logistic curve was generated using a likelihood method (non-linear estimation using STATISTICA v 6.0 software):

$$P = 1/[1 + exp\,(- r\,(L - L_{50}))]$$

where (P) is the percentage of individuals that escaped by size class, (L_{50}) is the 50% size class as the mean escape and r is a constant related to the steepness of the selection curve.

Selectivity was estimated on the basis of the experiments performed using grid B, and to that end an extra-codend (same mesh size) was attached in order to collect the specimens separated by the grid as well as the catch.

RESULTS

The size frequency distribution of all the hake caught in the experimental trials is shown in Figure 7. The size that separates the first modal component from the rest is situated at around TL = 15 cm, and consequently this length has been taken as the value for separating small hake (TL $\leq$ 15 cm) from large hake (TL $>$ 15 cm) in comparative analyses.

Figures 8 and 9 show the retention by haul of small (left) and large (right) hake through the different catches and grids. The differences between catches reflect the escapes. Table 2 shows a wider retention range for grid types A, C and D than for grid B. The performance of grid type B, shown in the lower left hand of Figure 8, was more efficient, with a range of escape of between 88.8 and 95% on four hauls (Table 2), and it differs statistically from the others (X^2, 3.165; *gl.*, 3; $p < 0.05$). The right hand side of Figures 8 and 9 indicates that there were few differences between the trawl rigs for large hake, that is, grid selectivity on large individuals

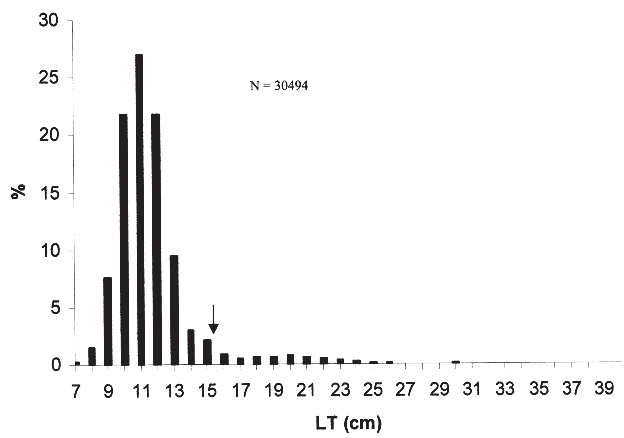

FIG. 7. – Pooled size frequency distribution of hake catches (TL, total length). The arrow indicates the TL separation between juveniles and the rest.

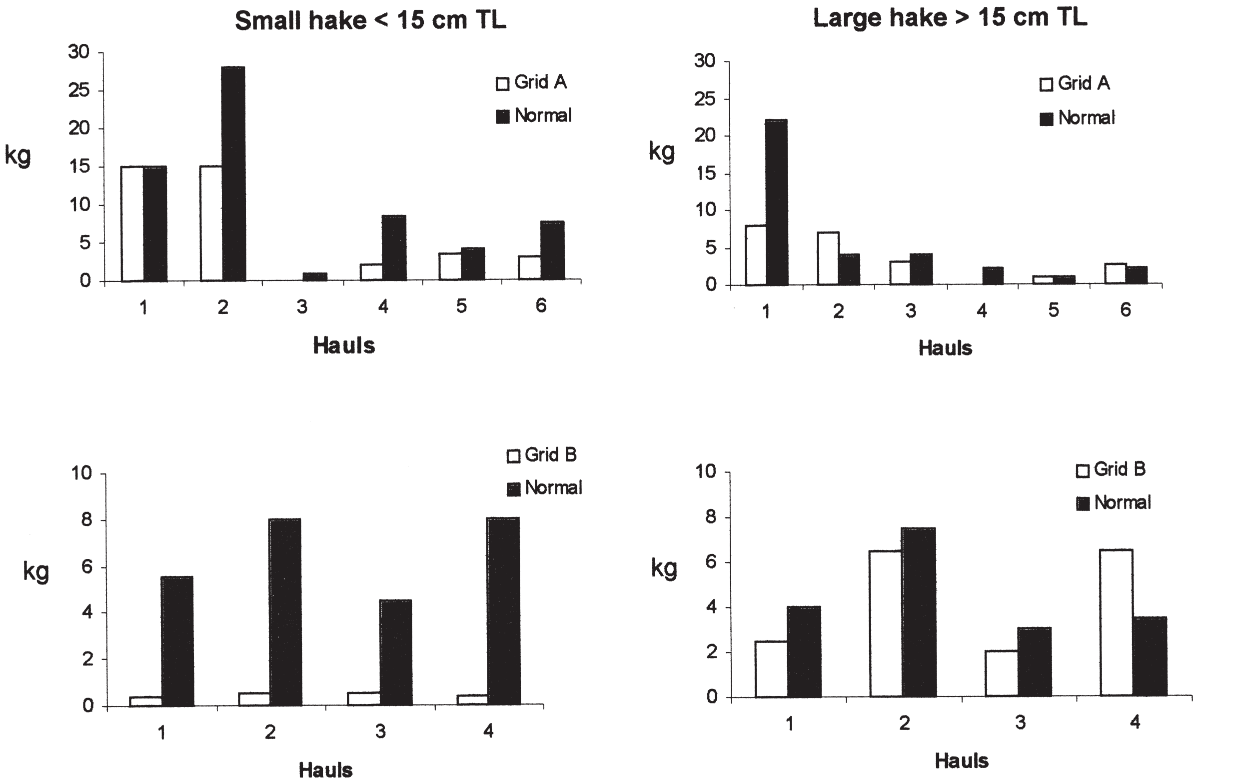

FIG. 8. – Retention for grid A and B. Left, small (LT ≤ 15 cm) hake. Right, large hake (LT>15 cm) compared with escape of the normal trawl. Height difference between columns represents the escapes.

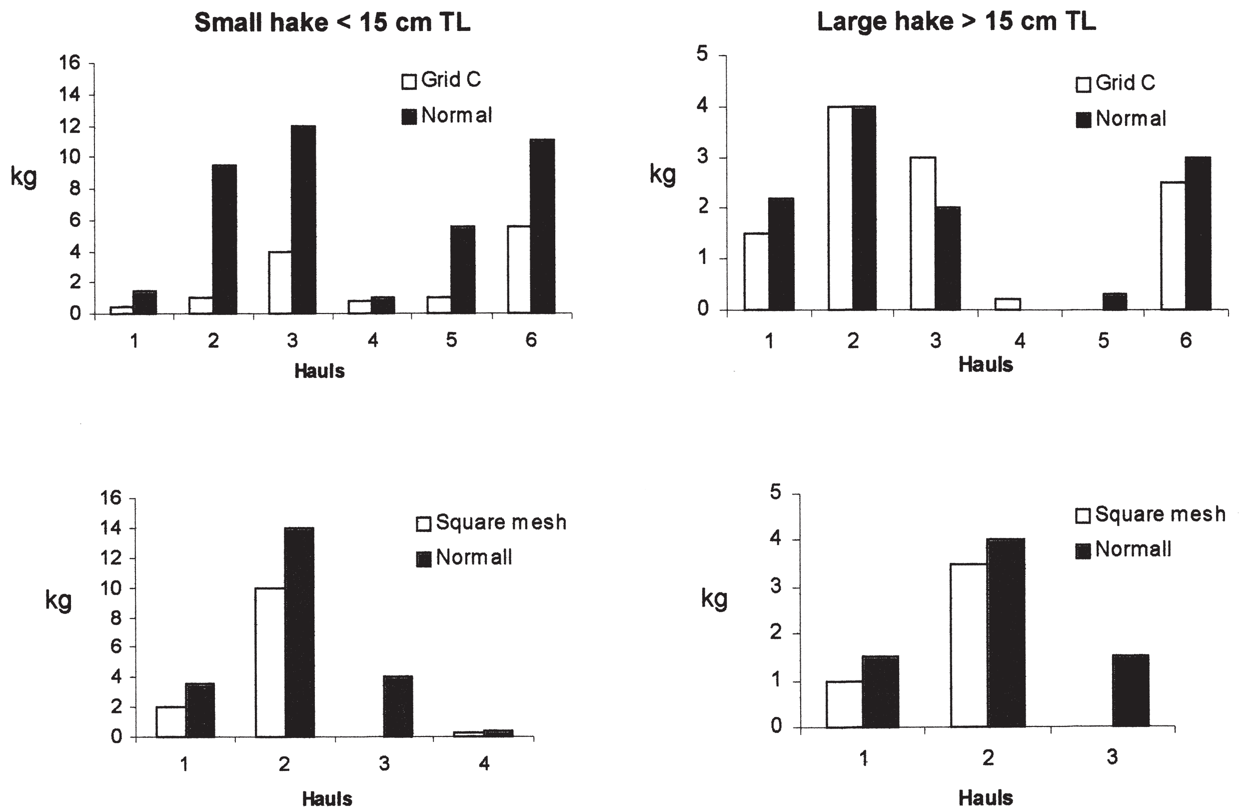

FIG. 9. – Retention for grid C and square mesh D. Left, small hake. (LT ≤ 15 cm). Right, large hake (LT > 15 cm) compared with escape of the normal trawl. Height difference between columns represents the escapes.

TABLE 2. – Percentage of efficiency in weight (kg) for small and large hake escapements by haul and grid type.

A	B	C	D
Small hake ≤ 15 cm TL			
0.0	92.7	66.7	42.9
46.4	93.7	89.5	28.6
100.0	88.8	66.7	100.0
76.4	95.0	20.0	50.0
17.5		81.8	
60.0		50.0	
Large hake > 15 cm TL			
63.6	37.5	31.8	33.3
-42.8	13.3	0.0	12.5
25.0	33.3	-33.3	100.0
100.0	-46.1	-100.0	
0.0		100.0	
-20.0		16.6	

was very variable and some times the unmodified trawl gear caught more large hake than the trawl gear equipped with the exclusion device (negative values in Table 2), and hence the catches taken by the two rigs did not differ significantly (p>0.05). The comparison shows that grid types B and C were the most efficient ones, with a restricted range of variation. When comparing the values we need to bear in mind that the standard deviations are very variable, because each of the hauls differs greatly even from the replicate hauls made using the same gear, depending on random factors influencing how successful each haul was. On the other hand, the hauls was performed in a depth range of between 50 and 300 m, in which the size distribution of hake may differ.

Measurement of the individuals retained by the additional codend cover, attached to the trawl net fitted with grid type B, allowed comparison of the size of the hake that were actually able to escape through the mesh with those that were directed into the codend. The results have been plotted in Figure 10. The equation fit to the curve shows that L_{50} for escaping individuals (an escape rate of 50%) was 18.8 cm (TL), with the selection range of escaping individuals between 16.8 cm TL (L_{25}) and 20.9 cm TL (L_{75}).

The results yielded the following logistic equation for hake selection by bars spaced 20 mm apart:

$$P = 1/[1+ exp\ (-0.533(L\text{-}18.8))]$$

DISCUSSION

In general the use of the grids resulted in high escape rates for individuals which were not only immature but actually illegal to catch (in Spain the minimum legal size for hake is 20 cm TL). It is thus inferable that the use of a sorting grid is important not only for hake but also for many other species.

Bottom type differed between the 50 and 300 m isobaths, which also influenced the composition of the catches and hence affected the comparison of the repetitions. All these factors certainly contributed to the variability observed between hauls carried out using the same grid.

Another aspect that needs to be considered is the inherent variability of catches in the Mediterranean when short hauling times are used (Sardà *et al.*, 2002). In experiments performed in multispecies fisheries like the ones considered here, a balance needs to be struck between the time available for the trials and the time available for the repetitions to be carried out, according to the different grid types to be tested and the bottoms to be trawled. Thus, the

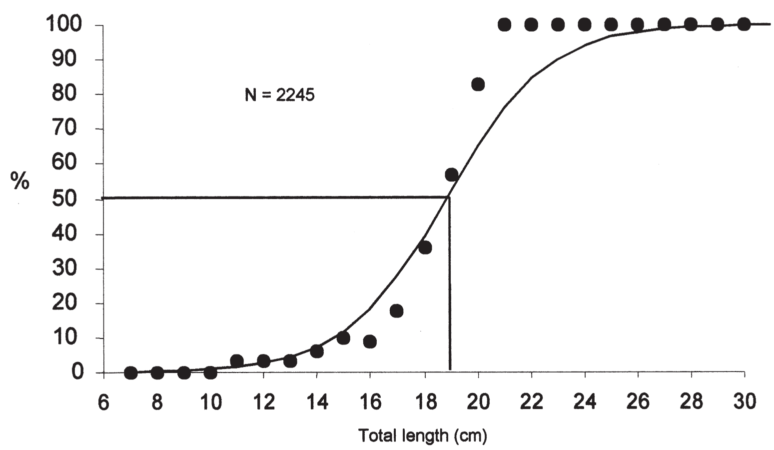

FIG. 9. – Percentage of retention and fit of logistic curve for hake, using grids with 20 mm spacing between bars.

variability will be influenced by fluctuations between the catches taken by hauls of short duration, and accordingly the capture of a given species which may or may not have formed aggregations depending on the time of day, weather, and current flow is to some extent a matter of “luck” (Sardà *et al.*, 2002).

The square mesh, which has been shown to allow more fish to escape than the diamond-shaped mesh, was less efficient than the grids. Massutí *et al.*, (2002) working with a codend of square mesh (20 mm side), obtained for hake an L_{50} of 15.3 cm TL, which corroborates the smaller selectivity of the square mesh compared with L_{50} from grids of 20 mm bar spacing.

Results for other countries and species have also been reported. In all cases grids designed specifically for a given species have been observed to outperform other grids and codend designs (Isaksen *et al.*, 1992; Anonymous, 1998). Nevertheless, direct comparison is difficult, because the design and the bar spacing have varied with the specific design for each individual fishery. For most fish species, however, performance rates greater than 50% have been recorded. Ercoli *et al.* (2000) obtained excellent results for Argentinean hake (*Merluccius hubsi*) using a grid similar to grid type B here and a bar spacing of 36 mm, attaining a 50% selection rate for a length of 35 cm, which is much higher than the values observed in these trials (a bar spacing of 20 mm and a 50% escape rate at 18.8 cm), and near to the length of first maturity for Mediterranean hake. In general, taken into account the multi-specific context of the Mediterranean fishery, sorting grid systems are more efficient than top panel of squared mesh systems, but these systems still involve some difficulties of handling. Diamond meshes are a non-effective system for improving the selectivity of Mediterranean hake. Campos and Fonseca (2003) obtained 18 cm of LT at L_{50} using an 80 mm stretch diamond mesh, which is not realistic for use in the Mediterranean fisheries.

In short, these trials have shown the grid systems to be effective at size sorting and relatively low in cost as compared to the total price of the gear. However, technical modifications to make system handling more practical on board the vessel are necessary, and this must be done by the interested companies. Potential new modifications should focus on achieving easy handling on deck and adapt flexible grids that can be rolled into the winch. New experiments should consider the efficiency of other designs of sorting grids for different regional and local fisheries, in addition to other target species and boat characteristics. In the future, the efficiency of the grids and square mesh can be dramatically improved by testing and modifying the internal conus of projection (length, diameter, and position) and the angle of the grid.

The European Community is increasingly turning to the use of selective systems to manage the fishery in the Mediterranean, and in this framework it will fall to the national administrations to promote the testing and use of sorting grids in trawl gears.

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